

09/03/99

jc674 U.S. PTO

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PATENT APPLICATION  
TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No. 112025-0167

First Inventor or Application Identifier Darren Kerr et al.

Title INSTRUCTION DECODE MECHANISM FOR PIPELINE STAGE  
REGISTER ADDRESSING

Express Mail Label No. EL024696651US

## APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility application contents

ADDRESS TO:

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1. ☒ \*Fee Transmittal Form (e.g., PTO/SB/17)  
(Submit an original and a duplicate for fee processing)
2. ☒ Specification [Total Pages 20]  
(preferred arrangement set forth below)

- Descriptive title of the invention
- Cross References to Related Applications
- Statement Regarding Fed sponsored R & D
- Reference to Microfiche Appendix
- Background of the Invention
- Brief Summary of the Invention
- Brief Description of the Drawings (if filed)
- Detailed Description
- Claim(s)
- Abstract of the Disclosure

3. ☒ Drawing(s) [Total Sheets 5]

4. Oath or Declaration [Total Pages 2]

- a. ☒ Newly executed (original copy)
- b. ☐ Copy from a prior application (37 C.F.R. § 1.63(d))  
(for continuation/divisional with Box 17 completed)

[Note Box 5 below]

## DELETION OF INVENTOR(S)

Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

5. ☐ Incorporation By Reference (useable if Box 4b is checked)  
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered to be part of the disclosure of the accompanying application and is hereby incorporated by reference therein

6. ☐ Microfiche Computer Program (Appendix)
7. Nucleotide and/or Amino Acid Sequence Sequence Submission  
(if applicable, all necessary)
- a. ☐ Computer Readable Copy
- b. ☐ Paper Copy (Identical to computer copy)
- c. ☐ Statement verifying identity of above copies

## ACCOMPANYING APPLICATION PARTS

8. ☒ Assignment Papers (cover sheet & document(s))
9. ☐ 37 C.F.R. § 3.73(b) Statement (when there is ☒ Power of Attorney an assignee)
10. ☐ English Translation Document (if applicable)
11. ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
12. ☐ Preliminary Amendment
13. ☒ Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
14. ☐ \*Small Entity Statement(s) ☐ Statement filed in prior application, Status still proper and desired (PTO/SB/09-12)
15. ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)
16. ☐ Other:

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17. If a CONTINUING APPLICATION, check appropriate box and supply the requisite information below and in a preliminary amendment.

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: /

Prior application Information: Examiner

Group/Art Unit:

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**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

In Re The Application of:	)	
Darren Kerr et al.	)	
Serial No.: Not Yet Assigned	)	Examiner: Not Yet Assigned
Filed: September 3, 1999	)	
For: INSTRUCTION DECODE	)	Art Unit: Not Yet Assigned
MECHANISM FOR PIPELINE	)	
STAGE REGISTER ADDRESSING	)	
	)	
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		September 3, 1999

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The following papers are being deposited with the United States Postal Service  
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<u>X</u> Patent Application ( 20 pages including 21 claims )	
<u>X</u> Declaration and Power of Attorney	<u>X</u> Fee Transmittal Letter
<u>X</u> Utility Patent Application Transmittal	<u>X</u> Assignment With Recordation Form
	Cover Sheet
<u>X</u> Informal Drawing ( 5 sheets )	<u>X</u> Check in the amount of \$760.00
<u>X</u> Check in the amount of \$40.00	

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*and*

for a

## ADDRESSING

## FIELD OF THE INVENTION

The present invention relates to processor architectures and, in particular, to an improved operand bypassing technique for a pipelined processing engine of an intermediate network device.

## BACKGROUND OF THE INVENTION

Computer architecture generally defines the functional operation, including the flow of information and control, among individual hardware units of a computer. One such hardware unit is the processor or *processing engine* which contains arithmetic and logic processing circuits organized as a set of data paths. In some implementations, the data path circuits may be configured as a processor having a register file of general-purpose registers (GPRs) for use with operations that are defined by a set of instructions. The instructions are typically stored in an instruction memory and specify a set of hardware functions that are available on the processor. When implementing these functions, the processor generally processes “transient” data residing in a memory in accordance with the instructions.

A high-performance processing engine configured for use in, e.g., an intermediate network device may be realized by using a number of identical processors to perform certain tasks in parallel. In order to increase instruction throughput, the processors of the high performance engine may employ a technique called pipelining. A pipelined processor has a pipeline containing a number of processing stages, such as an instruction fetch (IF) stage, an instruction decode (ID) stage, an execution (EX) stage and a writeback (WB) stage. These stages are generally arranged so that a new instruction is stored in an input register of each stage as the result calculated in that stage is stored in an input register of a subsequent stage. Accordingly, there may be a number of instructions active in the processor pipeline at any one time.

For example, consider the following instruction sequence utilizing various GPRs of the processor:

(i1) add R3  $\leftarrow$  R1, R2

(i2) add R5  $\leftarrow$  R3, R4

5        Execution of instruction **i1** results in register R3 storing the contents of R1 + R2, while execution of instruction **i2** results in R5 storing the contents of R3 + R4. Assume **i1** enters the pipeline at the IF stage in cycle 1 and proceeds to the ID stage at cycle 2 as **i2** enters the pipeline at the IF stage. During the ID stage, operand values are fetched from the register file of the processor. That is during the ID stage of **i1**, the values of the  
10        registers R1 and R2 are fetched from the register file and are loaded into input registers of the EX stage at the end of the IF stage cycle.

In cycle 3, **i2** reaches the ID stage and expects to load its operands from registers R3 and R4. However, **i1** has only reached the EX stage and will not complete the WB stage until the end of cycle 4. Accordingly, the correct operand for **i2** will not be loaded  
15        into register R3 until cycle 4 has completed. This is an example of data dependency between instructions executing in parallel in the pipeline. Here, the data dependency exists between the destination operand of **i1** and the source operand of **i2**; in other words, **i2** depends on a result produced by the preceding instruction **i1** and cannot proceed until that result (stored in R3) is available.

20        Commercially available pipeline processors employ *operand bypassing* to improve processing time for sequences of instructions that have data dependencies. Operand bypassing is a technique whereby an operation result may be used without waiting for that result to flow through all of the stages of a pipelined processor. An implementation of operand bypassing involves the use of a conventional control mechanism that employs  
25        a GPR operand comparison approach to identify the data dependency during the ID stage. For example the comparison may be used to determine a data dependency between the instructions **i1** and **i2** for register R3. Once the dependency is identified, the control mechanism provides the result of **i1** from the EX stage directly back to an input register of that stage, thereby bypassing the WB stage of the pipeline.

Where the data dependency is based solely on GPR registers, that dependency may be identified through use of a conventional scoreboarding technique that keeps track of the registers used by instructions propagating through the pipeline. The technique utilizes a scoreboard data structure having a plurality of bits associated with the GPRs; these bits are asserted when instructions utilizing the registers are dispatched into the pipeline. For example, the scoreboard technique marks register R3 as “not available” and the control mechanism suspends execution of i2 until R3 is available. Here, the conventional control mechanism “implicitly” specifies bypass conditions through instruction decode.

However, a problem arises with a processor architecture that also enables operands to address data from memory via a memory bus. Application of the conventional scoreboarding technique to memory addresses is rather cumbersome because of the additional “overhead” (logic) needed to realize the dependency function across an entire memory address space (e.g., a 32-bit address space). The present invention is directed to a technique that solves this problem. Specifically, the invention is directed to a pipeline stage addressing technique that obviates the need for a scoreboard data structure in the processor. More specifically, the present invention is directed to a technique for *explicitly* specifying bypass conditions in a manner that is efficient from a logic implementation and that reduces penalties from a microcode perspective.

## SUMMARY OF THE INVENTION

The present invention relates to a mechanism that enables an instruction to control data flow bypassing hardware within a pipelined processor of a programmable processing engine. The control mechanism is defined by an instruction set of the processor as a unique register decode value that specifies either source operand bypassing or result bypassing from a previous instruction executing in pipeline stages of the processor. The novel instruction decode control mechanism essentially allows an instruction to directly identify a pipeline stage register (i.e., via *pipeline stage register addressing*) for use as its source operand.

In one aspect of the present invention, the register decode value comprises a *result bypass* (RRB) operand that explicitly controls data flow within a pipeline of the processor through the use of result bypassing hardware of the processor. The pipeline generally includes instruction decode, writeback and execution stages, the latter stage having a plu-  
 5 rality of parallel execution units. Result bypassing allows data to be retrieved from a current execution unit and returned to an input execution register specified by the RRB operand, thereby bypassing “writeback” of the data to either a register file or memory at the writeback stage of the processor. By explicitly specifying the pipeline stage register to be used as the source operand for the current instruction, the invention obviates the need to  
 10 keep track of a large scoreboard addressing area and, thus, eliminates the need for a scoreboard data structure in the processor.

In another aspect of the invention, the register decode value comprises a *source bypass* (RISB) operand that allows source operand data to be shared among the parallel execution units of the pipelined processor. For example, source bypassing allows a sec-  
 15 ondary execution unit to receive data stored at an effective memory address specified by a displacement operand in a previous instruction executed by a main execution unit of the processor. This aspect of the invention improves performance of the processor, particularly for data received over a local bus from a memory of the processing engine. That is, source bypassing effectively allows realization of two memory references through the use  
 20 of a single bus operation over the local bus. In addition, the novel RISB decode value represents coding efficiencies since the operand may be encoded with substantially fewer bits than those needed for a displacement address.

Advantageously, the novel control mechanism increases performance of a pipe-  
 lined processor by enabling bypass operations without the use of dedicated hardware to  
 25 identify and resolve operand dependencies. The inventive control mechanism further allows greater coding efficiency since memory operand results can be bypassed via a special register reference as opposed to specifying a memory operand. Moreover, pipeline stage register addressing provides an efficient means to specify the use of a previous instruction result as a source operand for the instruction.

## BRIEF DESCRIPTION OF THE DRAWINGS

The above and further advantages of the invention may be better understood by referring to the following description in conjunction with the accompanying drawings in which like reference numbers indicate identical or functionally similar elements:

5 Fig. 1 is a block diagram of a computer network comprising a collection of interconnected communication media and subnetworks attached to a plurality of stations;

Fig. 2 is a schematic block diagram of intermediate station, such as a network switch, that may be advantageously used with the present invention;

10 Fig. 3 is a schematic block diagram of a programmable arrayed processing engine having a plurality of processor complex (PE) elements;

Fig. 4 is a schematic block diagram of a PE element comprising a microcontroller processor (TMC) core for use with the present invention;

Fig. 5 is a schematic diagram of a TMC instruction that may be advantageously used with the present invention; and

15 Fig. 6 is a schematic diagram of the TMC core that preferably embodies a multi-stage pipeline design that may be advantageously used with the present invention.

## DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

Fig. 1 is a block diagram of a computer network 100 comprising a collection of interconnected communication media and subnetworks attached to a plurality of stations. 20 The stations are typically computers comprising end stations 102, 112 and intermediate station 200. The intermediate station 200 may be a router or a network switch, whereas the end stations 102, 112 may include personal computers or workstations. The subnetworks generally comprise local area networks (LANs) 110 and 120, although the invention may work advantageously with other communication media configurations such as 25 point-to-point network links. Communication among the stations of the network is typically effected by exchanging discrete data frames or packets between the communicating nodes according to a predefined protocol. For the illustrative embodiment described herein, the predefined protocol is the Internet protocol (IP), although the invention could



be implemented with other protocols, such as the Internet Packet Exchange protocol, AppleTalk protocol or DECNet protocol.

Fig. 2 is a schematic block diagram of intermediate station 200 that, in the illustrative embodiment, is preferably a network switch. The switch generally performs layer 2 processing functions, such as “cut-through” operations wherein an entire frame does not have to be stored before transfer to a destination; in addition, switch 200 may implement layer 3 forwarding operations. It should be noted, however, that the intermediate station may also be configured as a router to perform layer 3 route processing. A feature of the inventive architecture described herein is the ability to program the station for execution of either layer 2 and layer 3 operations. To that end, operation of the switch will be described with respect to IP switching of packets, although the switch may be programmed for other applications, such as data encryption.

The switch 200 comprises a plurality of interconnected components including an arrayed processing engine 300, various memories, queueing logic 210 and network port interface cards 240. Operations of these components are preferably synchronously controlled by a clock module 270 although the arrayed elements of the processing engine may be operatively configured to function asynchronously. In the illustrative embodiment, the clock module 270 generates clock signals at a frequency of 200 megahertz (i.e., 5 nanosecond clock cycles) and globally distributes them via clock lines to the components of the switch.

The memories generally comprise random access memory (RAM) storage locations addressable by the processing engine and logic for storing software programs and data structures accessed by the components. An operating system, portions of which are typically resident in memory and executed by the engine, functionally organizes the switch by, *inter alia*, invoking network operations in support of software processes executing on the switch. It will be apparent to those skilled in the art that other memory means, including various computer readable media, may be used for storing and executing program instructions pertaining to the operation of the switch.

The arrayed processing engine 300 is coupled to a memory partitioned into a plurality of external memory (Ext Mem) resources 280. A buffer and queuing unit (BQU)

210 is connected to a packet memory 220 for storing packets and a queue memory 230 for storing network layer headers of the packets on data structures, such as linked lists, organized as queues 235. The BQU 210 further comprises data interface circuitry for interconnecting the processing engine with a plurality of line cards 240 via a selector circuit 250 having an arbiter 255. The line cards 240 may comprise, e.g., OC12, OC48 and Fast Ethernet (FE) ports, each of which includes conventional interface circuitry that incorporates the signal, electrical and mechanical characteristics, and interchange circuits, needed to interface with the physical media and protocols running over that media. A typical configuration of the switch may include many input/output channels on these interfaces, each of which is associated with at least one queue 235 in the queue memory 230. The processing engine 300 generally functions as a switching processor that modifies packets and/or headers in sequence as the BQU 210 implements queuing operations.

A routing processor (RP) 260 executes conventional routing protocols for communication directly with the processing engine 300. The routing protocols generally comprise topological information exchanges between intermediate stations to determine optimal paths through the network based on, e.g., destination IP addresses. These protocols provide information used by the RP 260 to create and maintain routing tables. The tables are loaded into the external partitioned memories 280 as forwarding information base (FIB) tables used by the processing engine to perform forwarding operations. When processing a header in accordance with IP switching, the engine 300 determines where to send the packet by indexing into the FIB using an IP address of the header. Execution of the forwarding operations results in destination media access control (MAC) addresses of the headers being rewritten by the processing engine to identify output ports for the packets.

Fig. 3 is a schematic block diagram of the programmable processing engine 300 that may be advantageously used with the present invention. The processing engine comprises a plurality of processing elements (PE) 400 arrayed into multiple rows and columns; in the illustrative embodiment, the PEs are arrayed as four (4) rows and four (4) columns in a 4 x 4 arrayed configuration that is embedded between an input header buffer (IHB) 360 and an output header buffer (OHB) 370. Note that other configurations, such

as a 6 x 6 arrayed configuration, may be used in advantageously used with the present invention.

A 64-bit feedback path 350 couples the OHB 370 to the IHB 360 and provides a data path for recycling data through the PE stages of the processing engine. The PEs of each row are configured as stages connected in series by a 100 MHz 64-bit direct memory access (DMA) data path 340 that synchronously transfers data and control “context” from one PE to the next. Specifically, the processing elements of each row are configured as stages of a pipeline that sequentially execute operations on the transient data loaded by the IHB 360, whereas the processing elements of each column operate in parallel to perform substantially the same operation on the transient data, but with a shifted phase. An example of an arrayed processing engine and network switch suitable for use with the present invention is described in copending and commonly-owned US Patent Application Serial No. 09/106,478 titled *Programmable Arrayed Processing Engine Architecture for a Network Switch*, which application is hereby incorporated by reference as though fully set forth herein.

Fig. 4 is a schematic block diagram of a PE 400. The PE is a processor complex comprising a processor 600 coupled to an instruction memory (IRAM) 420 and a memory manager (MM) circuit 430. The IRAM 420 stores instructions for execution by the processor 600, which is preferably a customized microcontroller (TMC) core having a dense structure which enables implementation of similar cores on an application specific integrated circuit. It will be apparent to those skilled in the art, however, that other processor cores may be advantageously used with the processor complex architecture described herein.

The TMC core 600 is preferably a pipelined processor that includes a plurality of arithmetic logic units (ALUs), a register file 615 having a plurality of 32-bit general purpose registers (GPRs) and an instruction fetch and decode unit organized as a set of data paths. The GPRs generally store intermediate result information processed by the ALUs, whereas the instruction fetch and decode unit decodes instructions fetched from the IRAM. The intermediate results are passed among PE stages 400 of the engine 300 over a consistent data path channel 340 provided by a data mover circuit 440 coupled to the

MM 430. The TMC also supports fast task context switching to enable software pipelining across multiple cores.

A 64-bit local bus 425 (comprising a read bus portion 424 and a write bus portion 426) interconnects the TMC core with context memories 435, a local memory 450 and a level zero (L0) cache 460 coupled to an external memory I/F 310. The local bus 425 can sustain one 64-bit read operation and one 64-bit write operation per cycle for data aligned on a 4-byte boundary. The maximum sustainable rate for non-aligned data accesses is one 32-bit read operation and one 32-bit write operation per clock cycle. The TMC core may directly access locations in the context memories 435 and the local memory 450 using an operand address associated with an instruction. Notably, the context memories 435 and the local memory 450 support zero wait state non-aligned accesses; accordingly, there is generally no performance difference when accessing data in those memories or the internal registers of the TMC core.

Each context memory 435 stores transient “context” data (e.g., packet/frame data) flowing through the PE 400 that is unique to a specific process, whereas the local memory 450 is generally configured to store, *inter alia*, pointers that reference data structures and tables stored in external memory 280 for use by the TMC core 600. Management of the context sensitive memory is provided by the MM 430, which comprises data path and control logic for cooperating with the data mover 440 and context memories 435 to efficiently pass data among the PE stages of the processing engine. The L0 cache 460 may be a fully associative, multiport data cache that services external memory 280 and a shared column memory (not shown); notably, the L0 cache provides various caching and buffering functions for those memories, and may further issue specific memory primitives to the appropriate memory controller of either the external or internal shared memory to thereby increase the overall bandwidth and efficiency of the TMC 600.

The TMC architecture incorporates a VLIW design capable of executing more than one instruction per cycle through the use of multiple execution units performing multiple scalar operations in parallel. The execution units are a main execution unit (M-unit) and a secondary execution unit (S-unit). As noted, the TMC processor architecture enables operands to address data from, e.g., local memory 450 via the local bus 425;

however a difference between the two execution units is that the S-unit does not directly address memory. Parallel operation of execution units increases the processing performance of the switch while also decreasing the number of data transfers over the local bus. For such a design, an instruction decoder determines whether an execution unit is ready  
 5 for operation. The TMC architecture utilizes a wide instruction that explicitly schedules operation of the execution units.

In the illustrative embodiment, the TMC core 600 uses a 64-bit instruction word to operate on multiple 32-bit data values. Logical operations are performed on indirect memory operands to improve the overall density of the instruction code by merging  
 10 arithmetic instructions with load/store instructions into one instruction. Broadly stated, multiple opcodes of differing widths can be encoded in a fixed length instruction word. Each instruction word contains two major opcodes and up to three minor opcodes (micro-ops) that execute in parallel. Instruction level parallelism is scheduled by software as opposed to hardware, thereby eliminating the need for hardware-based schedulers while  
 15 enabling completion of multiple instructions per cycle. An instruction set architecture provides micro-opcodes to initiate memory prefetches without requiring a dedicated instruction.

Each instruction generally includes two primary opcodes, one of which is directed to the M-Unit (e.g., M add) and the other which is directed to the S-Unit (e.g., S and). As  
 20 noted, each opcode executes concurrently on its respective unit and in parallel with the other. Fig. 5 is a schematic diagram of a TMC instruction 500 comprising a 32-bit A part 502 containing an opcode directed to the M-Unit, a 22-bit B part 504 containing an opcode issued to the S-Unit (or branch unit), and a 10-bit C part 506 comprising three micro-opcode fields. From an instruction decode perspective, the S-Unit does not have direct  
 25 access to the local bus 425 primarily because a (displacement) operand requires 12 bits to encode in displacement form and the TMC architecture does not define that quantity of bits for an S-Unit instruction.

Fig. 6 is a schematic diagram of the TMC core 600 which preferably embodies a multi-stage pipeline data path organization comprising (i) an instruction fetch (IF) stage  
 30 610; (ii) an instruction decode (ID) stage 620; (iii) an execution (EX) stage 630; and (iv)

a writeback (WB) stage 660. The EX stage includes a main execution unit (M-unit 640) and a secondary execution unit (S-Unit 650) that are similar with respect to their execution logic. That is, the M-Unit 640 comprises a plurality of interstage registers M-ISR1A 642 and M-ISR1B 644 coupled to inputs of a M-ALU 646; likewise, the S-Unit 650  
 5 comprises interstage registers S-ISR1A 652 and S-ISR1B 654 coupled to inputs of a S-ALU 656.

According to the TMC micro-architecture, the M-Unit 640 is configured to communicate directly with memory over the local bus 425, whereas the S-Unit 650 is directed primarily to register-type operations (which can also be performed by the M-Unit). To  
 10 that end, memory operands may be retrieved from the read local bus 424, stored in M-ISR1B 644 and provided to the B input of the M-ALU 646, while intermediate (e.g., GPR) operands are stored in M-ISR1A 642 and provided to the A input of that logic unit. In contrast, only intermediate operands may be stored in S-ISR1A 652 and S-ISR1B 654, and provided to A and B inputs of S-ALU 656, respectively. Although data received by  
 15 the TMC core 600 over the read bus 424 is directed solely to the M-Unit 640, the TMC architecture includes a bypass mechanism comprising, in part, multiplexer 658 that allows the S-Unit 650 to share such data with the M-Unit.

The WB stage 660 comprises a plurality of registers, including M-WBR 662 coupled to the output of M-ALU 646 and S-WBR 664 coupled to the output of S-ALU 656.  
 20 Outputs of these registers are provided to the register file 615. For instructions that specify the register file as the destination of the data, the write-back actually occurs during the EX stage. Another interstage register ISR2 666 is coupled to M-WBR 662 and configured to store data that is destined for the write local bus 426.

Functionally, the IF stage accommodates accesses to the IRAM to acquire instructions. The ID stage fetches information (such as source operands) from memory over the  
 25 read local bus 424 or from the internal register file 615 for temporary storage in M-ISR1B, whereas source operands fetched from only the register file are stored in M-ISR1A, S-ISR1A and S-ISR1B. The fetched information flows through the EX stage of TMC execution units for processing and then to the WB stage for storage in M-WBR or  
 30 S-WBR prior to transfer to the register file 615. For information destined to either the

L0 cache 460, the context memories 435 or to the local memory 450, ISR2 is employed to store that information prior to transfer over the write local bus 426. Within this context, the invention is directed, in part, to the EX and WB stages.

Broadly stated, the invention is directed to use of *operand bypassing* to improve processing time for sequences of instructions that have data dependencies. A typical implementation of operand bypassing involves the use of a conventional control mechanism that employs GPR operand comparison and a scoreboard to identify data dependencies during the ID stage. The conventional control mechanism “implicitly” specifies bypass conditions through instruction decode. However, a problem arises with a processor architecture, such as the TMC architecture, that enables operands to address data from memory. Application of conventional scoreboarding techniques to memory addresses requires additional “overhead” (logic) to realize the dependency function across the memory address space. The present invention is directed to a pipeline stage addressing technique that obviates the need for a scoreboard data structure in the processor.

Consider the following instruction with implicit bypassing:

(i3) add 10(R3)  $\leftarrow$  R5, R2

(i4) add R1  $\leftarrow$  R7, 10(R3)

There is a dependency on the displacement memory operand 10(R3). This dependency may be identified using address comparison logic of the conventional control mechanism. In accordance with the present invention, however, the same function may be achieved via a pipeline stage register addressing technique that allows an instruction to directly identify a pipeline stage register for use as its source operand without the need for address comparison logic. The addressing technique is an integral part of a novel control mechanism defined by an instruction set of the TMC processor as a unique register decode value that specifies either source operand bypassing or, as indicated above, result bypassing from a previous instruction executing in pipeline stages of the processor.

In one aspect of the present invention, the register decode value comprises a *register result bypass* (RRB) operand that explicitly controls data flow within the pipeline of the TMC processor 600 through the use of result bypassing hardware of the processor.

(i3)  $\text{add } 10(R3) \leftarrow R5, R2$

(i4')  $\text{add } R1 \leftarrow R7, RRB$

Rather than actually specifying the memory operand 10(R3), the RRB operand explicitly infers feedback of data delivered from a current execution unit (e.g., M-unit) back to an input execution register (e.g., M-ISR1A) over feedback path 670, thereby bypassing write-back of the data to either the register file 615 or to ISR2 of the WB stage. In addition to bypassing results of a memory operation operand (e.g., an address) and GPR, the novel RRB operand enables bypassing of results of a transform register (e.g., a register internal to the TMC processor). By explicitly specifying the pipeline stage register to be used as the source operand for a current instruction, the invention obviates the need to keep track of a large scoreboard addressing area. This, in turn, eliminates the need for any scoreboard structure in the design of the TMC processor. Elimination of such a data structure is significant because of the dense population of logic on the TMC processor. Moreover, the RRB operand allows i4' to be encoded with fewer instruction bits. That is, the novel RRB operand is preferably encoded using 4 bits as opposed to 12 bits needed for a displacement operand.

It should be noted that the term *RRB* is encoded in accordance with an assembler mnemonic wherein the first *R* denotes a register operand, and the subsequent *RB* denotes the result to be bypassed. Furthermore the term *RRB* denotes the current execution unit, whereas the term *RIRB* (i.e., inter-unit result bypass) denotes the alternate execution unit. It should also be noted that the data dependency referred to herein exists between a destination operand of a previous instruction and a source operand of a subsequent instruction.

In accordance with the present invention, a result in either the current (main) execution unit or the alternate (secondary) execution unit can be bypassed. That is, data can be bypassed from either the M-Unit or the S-Unit and be used as an input operand value to those units. The invention thus comprises, in part, an explicit result bypassing mechanism that obviates the use of scoreboarding structures for maintaining data dependencies with respect to addresses originating from memory. The performance realized in a pipeline processor as the result of resolving data dependencies using the novel RRB operand is



the same as that achieved by a pipeline processor having a scoreboarding structure to resolve such dependencies.

In another aspect of the invention, the register decode value comprises a *source bypass* (RISB) operand that allows source operand data to be shared among the parallel execution units (e.g., the M-Unit and S-Unit) of the pipelined TMC processor. For example, source bypassing allows the secondary S-Unit 650 to receive data stored at an effective memory address specified by a displacement operand in a previous instruction executed by the main M-Unit 640 of the TMC 600. The source bypassing mechanism involves sharing of the output of M-ISR1B 644 with the S-Unit by way of multiplexer 658. Assume packet data is fetched by the ID stage 630 over the read local bus 424 for processing by the M-Unit. Assume further that the following instructions are executed at the TMC:

(i5) M add R1  $\leftarrow$  R2, 5(R3)

(i6) S and R2  $\leftarrow$  RISB, R3

The M add instruction is executed by the M-Unit and directed to a particular byte (8 bits) within the data field specified by the memory operand 5(R3). This memory operand is decoded as a displacement operand and translated to an effective address that is driven over the local bus 425. The local bus transfers at least 32 bits of (non-aligned) data and, in this case, only 8 bits of that data will be operated upon by the instruction i5. Yet, the remaining 24 bits transferred over the local bus may be useful for subsequent instruction execution. It would thus be desirable to share that data among the multiple execution units. Source operand bypassing allows the S-Unit to receive data starting at the effective memory address specified by the displacement operand in the previous M add instruction i5. This is denoted by the i6 (S and) instruction and, in particular, the use of RISB source operand bypassing.

In accordance with the present invention, the source bypassing mechanism improves performance of the TMC processor 600, particularly for data received over the local bus 425 from a memory of the processing engine 300. That is, source bypassing allows realization of two memory references through the use of a single bus operation

over the local bus. The RISB operand represents the data retrieved from the bus and is equivalent to the displacement operand address in the previous **i5** (M add) instruction. In addition, the novel RISB decode value represents substantial coding efficiencies since it may be encoded with substantially fewer bits than those needed for a displacement address. For example, the RISB operand requires only 4 bits as opposed to the 12 bits necessary for the displacement address.

An advantage of the novel control mechanism is the increase in performance of a pipelined processor by enabling bypass operations without the use of dedicated hardware to identify and resolve operand dependencies. The inventive control mechanism further allows greater coding efficiency since memory operand results can be bypassed via a special register reference as opposed to specifying a memory operand. Moreover, pipeline stage register addressing provides an efficient means to specify the use of a previous instruction result as a source operand for the instruction.

The foregoing description has been directed to specific embodiments of this invention. It will be apparent, however, that other variations and modifications may be made to the described embodiments, with the attainment of some or all of their advantages. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

What is claimed is:

## CLAIMS

1 1. Apparatus for enabling an instruction to control data flow bypassing hardware within  
 2 a processor of a programmable processing engine, the apparatus comprising:  
 3 a pipeline of the processor, the pipeline having a plurality of stages including in-  
 4 struction decode, writeback and execution stages, the execution stage having a plurality  
 5 of parallel execution units; and  
 6 an instruction set of the processor, the instruction set defining a register decode  
 7 value that specifies one of source operand bypassing and result bypassing from a previ-  
 8 ous instruction executing in pipeline stages of the processor.

1 2. The apparatus of Claim 1 further comprising:  
 2 a register file containing a plurality of general-purpose registers for storing inter-  
 3 mediate result data processed by the execution units; and  
 4 a memory for storing one of transient data unique to a specific process and point-  
 5 ers referencing data structures.

1 3. The apparatus of Claim 2 wherein the register decode value comprises one of a result  
 2 bypass (RRB) operand and an inter-unit result bypass (RIRB) operand, each of which ex-  
 3 plicitly controls data flow within the pipeline of the processor.

1 4. The apparatus of Claim 3 wherein the execution units comprise a current execution  
 2 unit and an alternate execution unit, and wherein the RRB operand denotes the current  
 3 execution unit and the RIRB operand denotes the alternate execution unit.

1 5. The apparatus of Claim 3 wherein the RRB operand explicitly infers feedback of the  
 2 data delivered from a current one of the execution units to an input register of the current  
 3 execution unit over a feedback path.

1 6. The apparatus of Claim 5 wherein the writeback stage comprises an interstage register  
2 and wherein the RRB operand enables bypassing write-back of the data processed by the  
3 execution units to one of the register file or the interstage register of the writeback stage.

1 7. The apparatus of Claim 2 wherein the register decode value comprises a source bypass  
2 (RISB) operand that allows source operand data to be shared among the parallel execu-  
3 tion units of the pipelined processor.

1 8. The apparatus of Claim 7 wherein the execution units comprise a main execution unit  
2 and a secondary execution unit, and wherein the RISB operand allows the secondary exe-  
3 cution unit to receive data stored at an effective memory address specified by a displace-  
4 ment operand in the previous instruction executed by the main execution unit.

1 9. A method for enabling an instruction to control data flow bypassing hardware within a  
2 pipelined processor of a programmable processing engine, the method comprising the  
3 steps of:

4 defining a register decode value that specifies one of source operand bypassing  
5 and result bypassing from a previous instruction executing in pipeline stages of the proc-  
6 essor; and

7 identifying a pipeline stage register for use as a source operand in an instruction  
8 containing the register decode value.

1 10. The method of Claim 9 further comprising the step of explicitly controlling data flow  
2 within the pipeline stages of the processor through use of a register result bypass (RRB)  
3 operand.

1 11. The method of Claim 10 wherein the pipeline stages include instruction decode,  
2 writeback and execution stages, and wherein the execution stage comprises multiple par-  
3 allel execution units including a current execution unit and an alternate execution unit.

1 12. The method of Claim 11 wherein the step of explicitly controlling comprises the  
2 steps of:  
3 retrieving data from the current execution unit; and  
4 returning the data to an input execution register specified by the RRB operand,  
5 thereby bypassing write-back of the data to either a register file or memory at the write-  
6 back stage.

1 13. The method of Claim 12 wherein the step of identifying further comprises the steps  
2 of:  
3 explicitly specifying the pipeline stage register to be used as the source operand  
4 for the instruction; and  
5 obviating need to keep track of a scoreboard addressing area.

1 14. The method of Claim 13 wherein the step of obviating comprises the step of elimi-  
2 nating the need for a scoreboard data structure in the pipelined processor.

1 15. The method of Claim 14 further comprising the step of sharing source operand data  
2 among the parallel execution units of the pipelined processor through the use of a source  
3 bypass (RISB) operand.

1 16. The method of Claim 15 wherein the step of sharing comprises the step of receiving  
2 data at the alternate execution unit, the data stored at a memory address specified by a  
3 displacement operand in a previous instruction executed by the current execution unit of  
4 the processor.

1 17. The method of Claim 16 wherein the step of sharing further comprises the step of  
2 realizing two memory references through the use of a single bus operation over a local  
3 bus.

1 18. The method of Claim 17 wherein the step of sharing further comprises the step of  
2 encoding the RISB operand with substantially fewer bits than those needed for a dis-  
3 placement address.

1 19. A computer readable medium containing executable program instructions for ena-  
2 bling an instruction to control data flow bypassing hardware within a pipelined processor  
3 of a programmable processing engine, the executable program instructions comprising  
4 program instructions for:

5 defining a register decode value that specifies one of source operand bypassing  
6 and result bypassing from a previous instruction executing in pipeline stages of the proc-  
7 essor; and

8 identifying a pipeline stage register for use as a source operand in a current in-  
9 struction containing the register decode value.

1 20. The computer readable medium of Claim 19 further comprising program instructions  
2 for explicitly controlling data flow within the pipeline stages of the processor through use  
3 of a register result bypass operand.

1 21. The computer readable medium of Claim 20 further comprising program instructions  
2 for sharing source operand data among parallel execution units of the pipelined processor  
3 through the use of a source bypass operand.

### ABSTRACT OF THE DISCLOSURE

An instruction decode mechanism enables an instruction to control data flow by-passing hardware within a pipelined processor of a programmable processing engine.

The control mechanism is defined by an instruction set of the processor as a unique register decode value that specifies either source operand bypassing (via a source bypass operand) or result bypassing (via a result bypass operand) from a previous instruction executing in pipeline stages of the processor. The source bypass operand allows source operand data to be shared among the parallel execution units of the pipelined processor, whereas the result bypass operand explicitly controls data flow within a pipeline of the processor through the use of result bypassing hardware of the processor. The instruction decode control mechanism essentially allows an instruction to directly identify a pipeline stage register for use as its source operand.

1/5

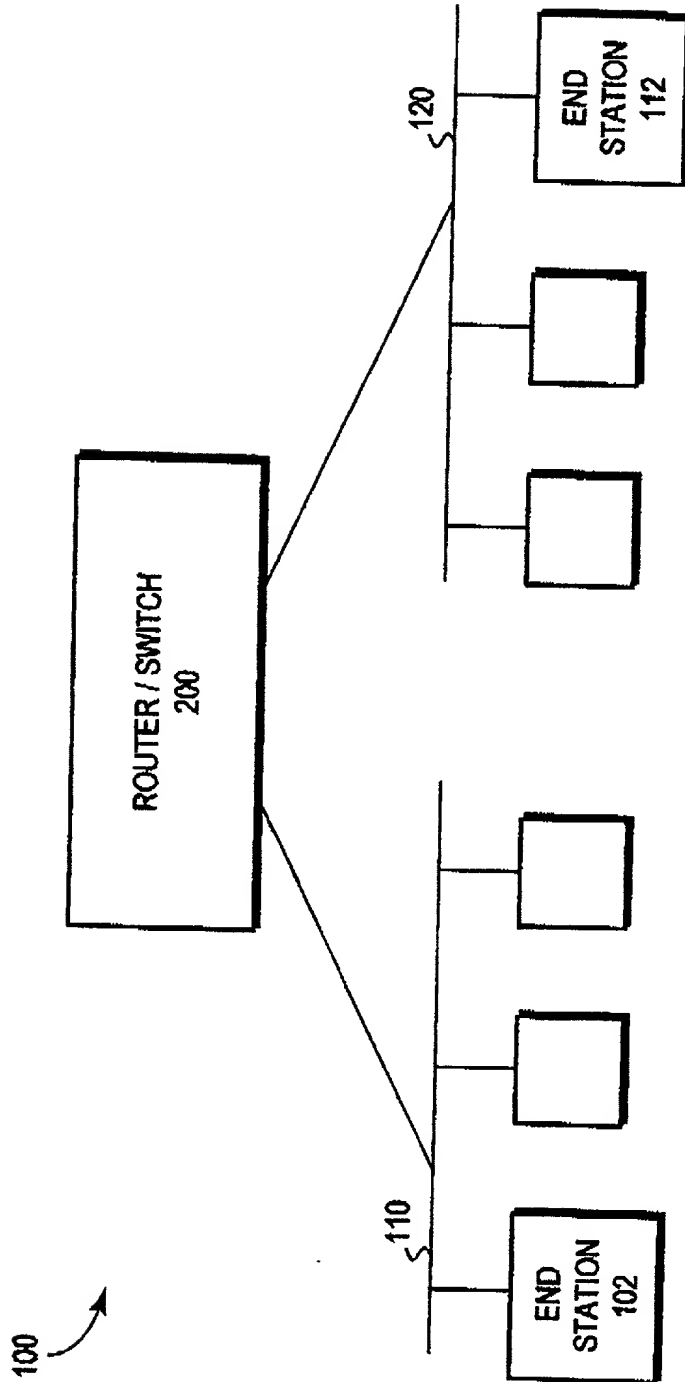


FIG. 1



2/5

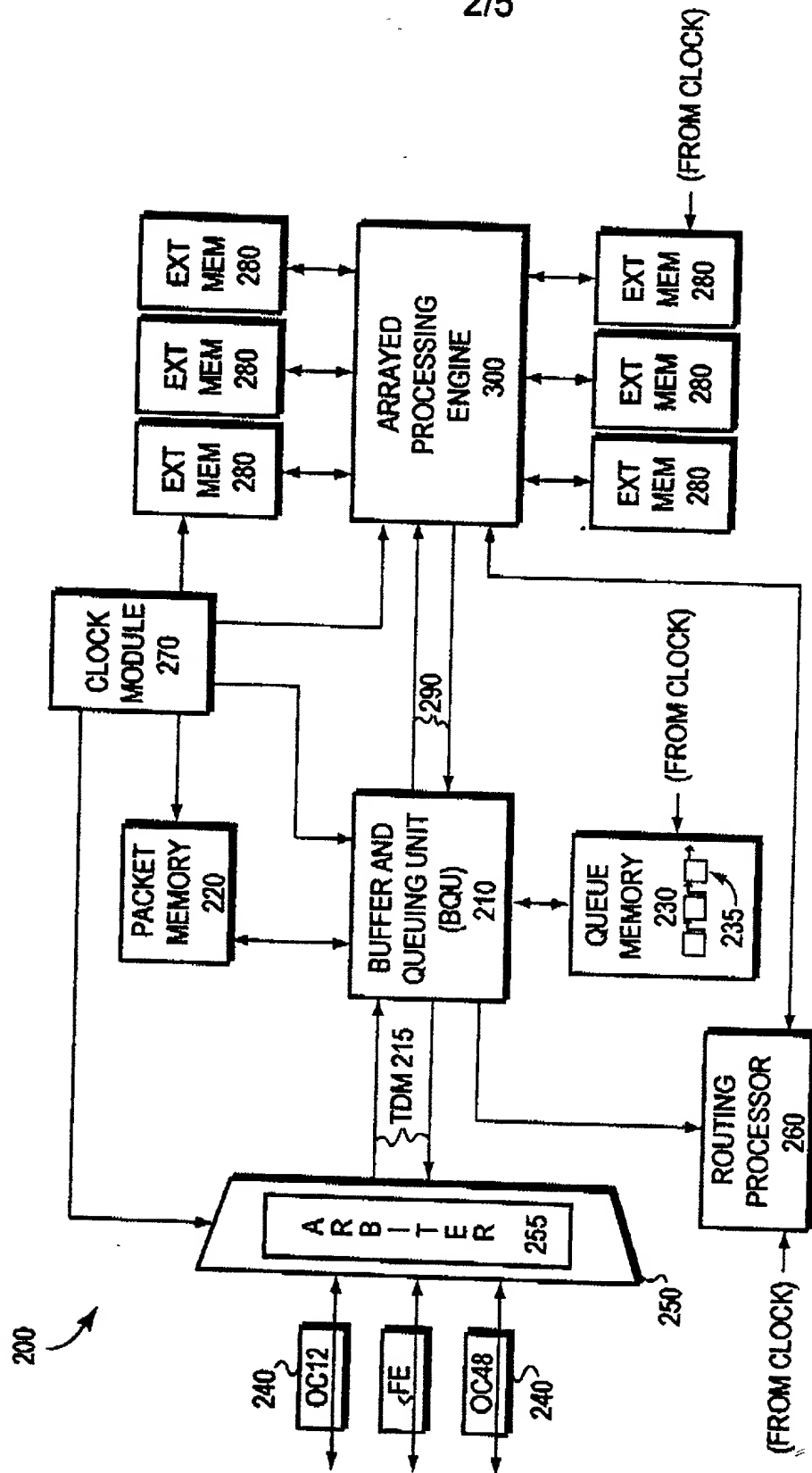


FIG. 2

3/5

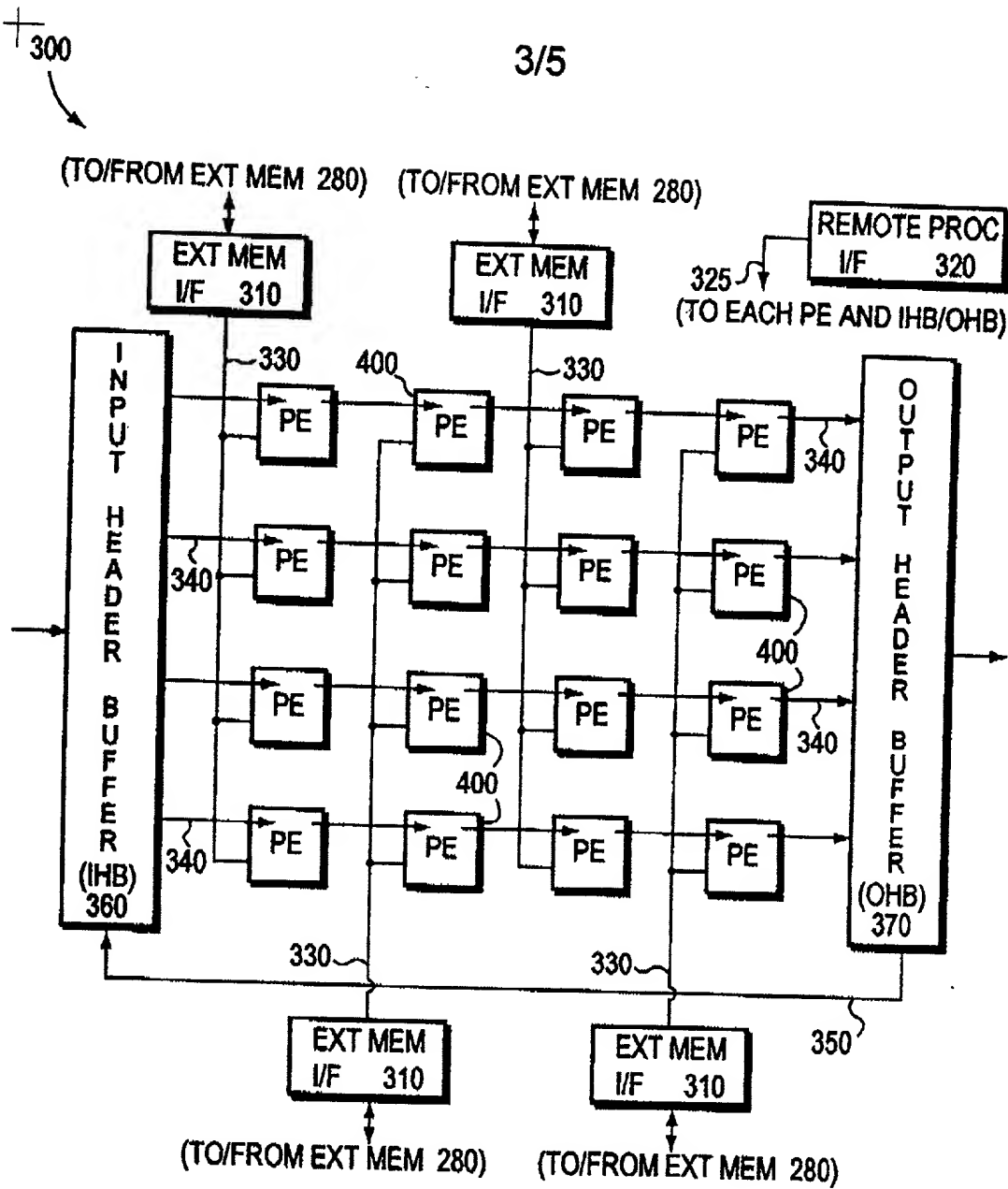


FIG. 3

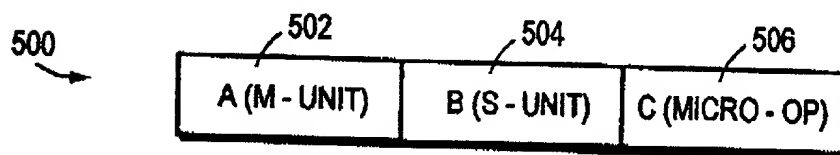


FIG. 5

4/5

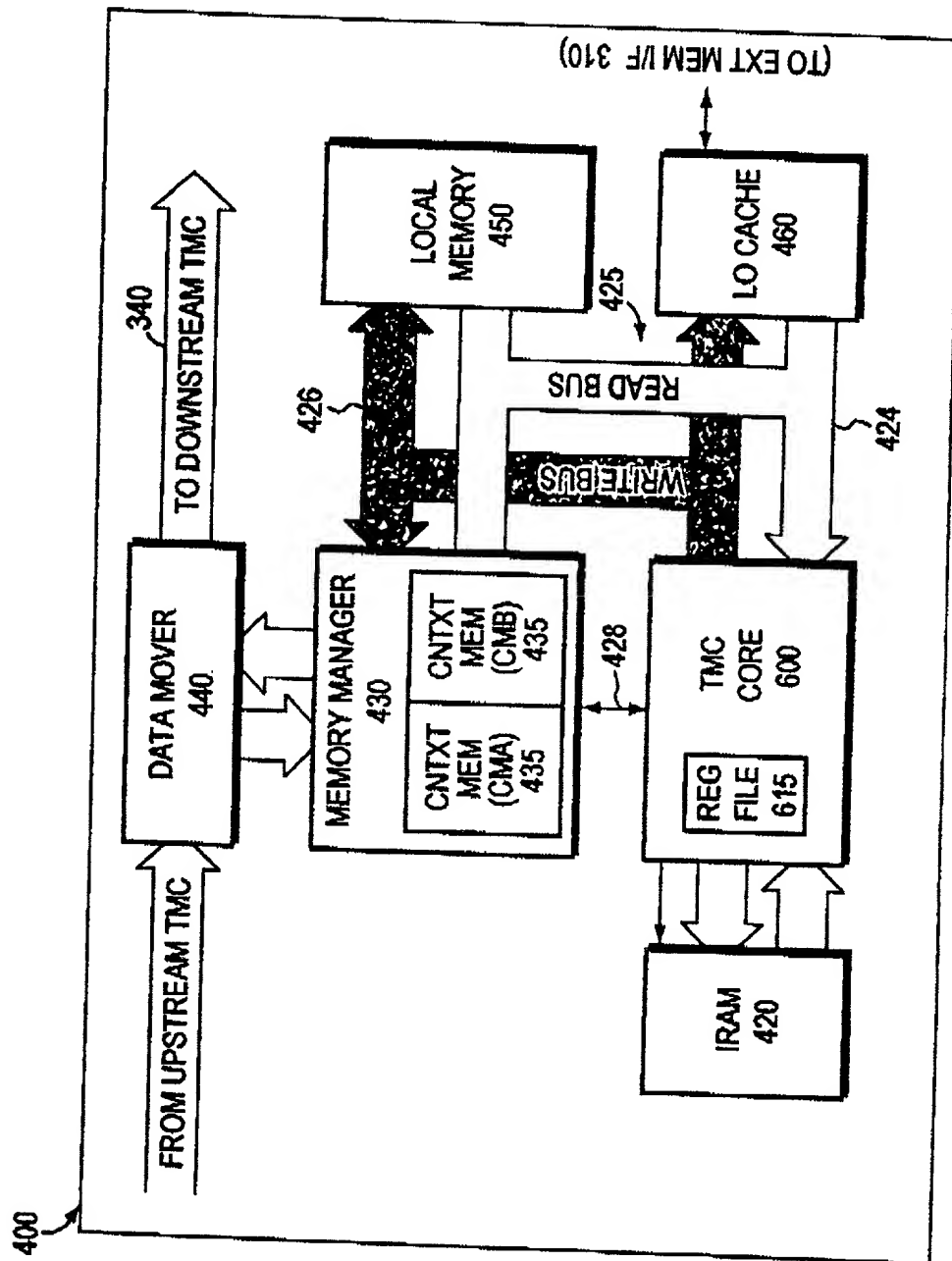


FIG. 4

5/5

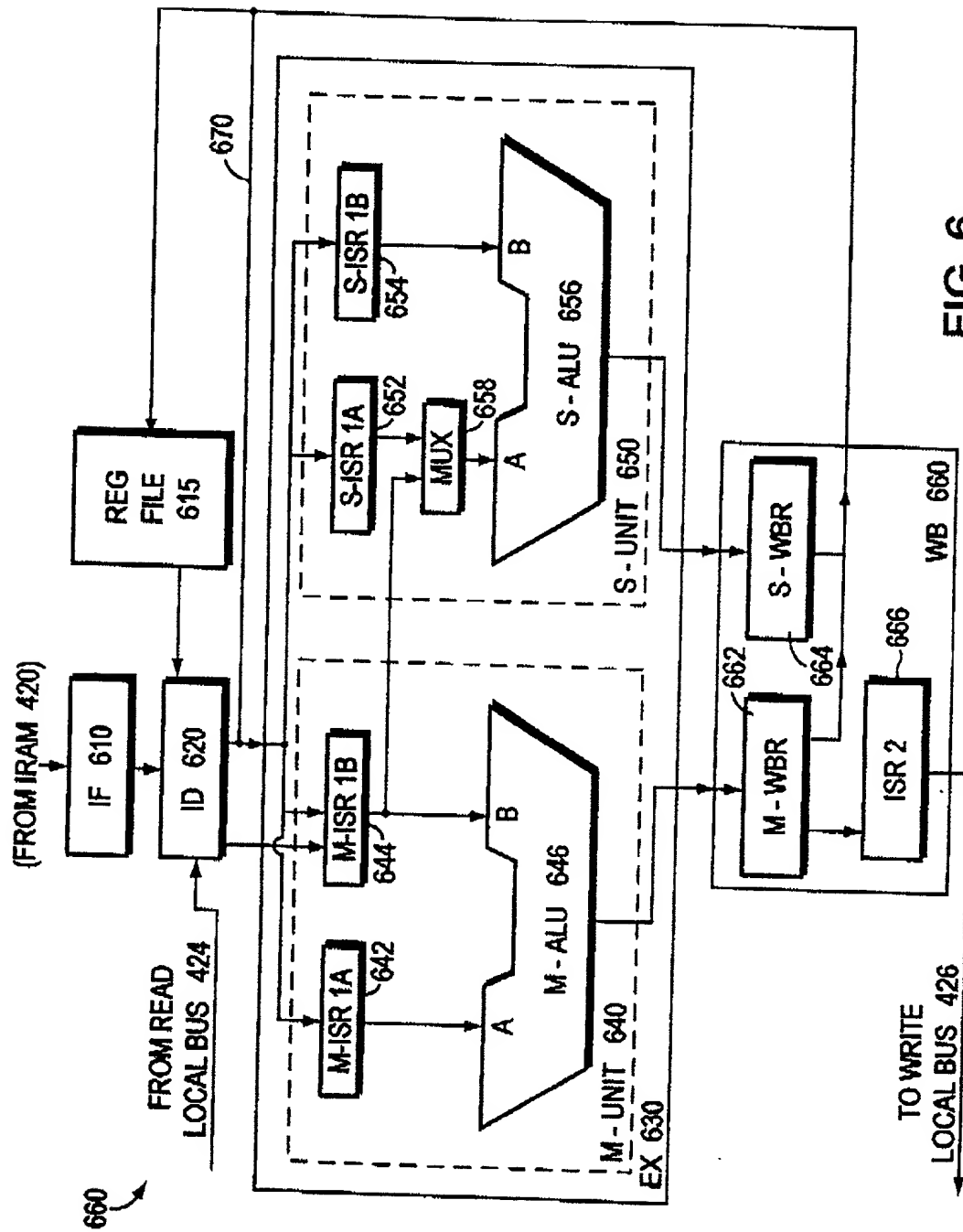


FIG. 6

## DECLARATION FOR PATENT APPLICATION

As a below-named inventor, I hereby declare that:

My residence, post-office address, and citizenship are as stated below next to my name.

I believe I am an original, first, and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled INSTRUCTION DECODE MECHANISM FOR PIPELINE STAGE REGISTER ADDRESSING, the specification of which is attached hereto and identified by Cesari and McKenna File No. 112025-0167.

I hereby state that I have reviewed and understand the contents of the above-identified application specification, including the claims, as amended by any amendment specifically referred to herein.

I acknowledge the duty to disclose all information known to me that is material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate filed by me on the same subject matter having a filing date before that of the application on which priority is claimed: None.

I hereby claim the benefit under Title 35, United States Code §119(e) of the following U.S. provisional application: None.

I hereby claim the benefit under Title 35, United States Code §120, of the United States Application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose all information that is material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56, and which became available to me between the filing date of the prior application and the national or PCT international filing date of this application: None.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Darren Kerr

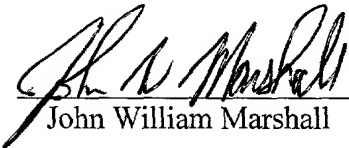
9-2-99

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